

**Review Article**

Slaking Lime for Restoration and Conservation of Historical Buildings and Materials, Criticism of an Arabic Historical Manuscripts

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Abstract: Slaking lime is an important and effective process for preparing mortars in conservation of historical buildings and archaeological artifacts based on lime. The lime mortars have been widely used since the Roman era, and lime became one of the important materials for conservation and restoration process to keep the authenticity of the historical materials and sustainability. In many cases, some conservators use black and white cement separately or mix with lime in conservation and restoration, or mix gypsum with lime. They think that will improve the strength of mortars, but all those procedures give bad results on the properties of the mortars, and cause irreversible deterioration for historical materials in both layers and surfaces. Through the mentioned problems, we should go back to historical documents to identify the best method for slaking process to get best results in any intervention needs lime mortars. So we depend on three historical resources from 13th A. H century the first historical manuscript entitled "message in architecture) preserved in king Saud university No.3392 without any previous criticism, the second European historical book entitled" all kinds of Roman cement) translated to Arabic in 1829 AD, the third Arabic book entitled" Summary of ideas in architecture), those resources presented all methods of slaking to give information for researchers to evaluate slaking process after experimental studies which depend on several factors, the main target of the research is to provide conservators with information about slaking process for preparing mortars with good properties in all conservation interventions in artefacts and historical buildings.

Keywords: Lime, Slaking, Burning, Roman Cement, Conservation, Mortars, Historical

1. Introduction

This paper gives information about all methods of burning and slaking lime as mentioned in historical documents from 13th century A. H to survey different methods of slaking lime, in order to choose the original methods, which used in the past to be adequate in restoration and conservation process in both historical buildings and archaeological artefact, lime mortars are usually more appropriate and similar, in terms of their permeability and hardness, to the heritage lime mortars to be restored [1].

Lime is considered one of the most important components of

traditional mortars [2]. It was used in building process, plastering, rendering layers for wall buildings [3]. and in conservation process of the historical and archaeological heritage, which was depend on lime and its component in the past, getting lime for mortars takes circle start with transferring lime stone or other sources of lime, burning process and slaking. (Figure. 1) shows lime circle [4]. Due to shortage of knowledge about lime slaking [5]. some conservators and contractors constrained to use lime without right slaking process, sometimes they use pre-packaged lime. The product companies write in specification of lime that it was slaked but this is not enough because there are different uses for each slaking process

and there are other effective factors like the duration of slaking, the components of lime, the source of lime, the burning process, burning materials and the temperature of burning.

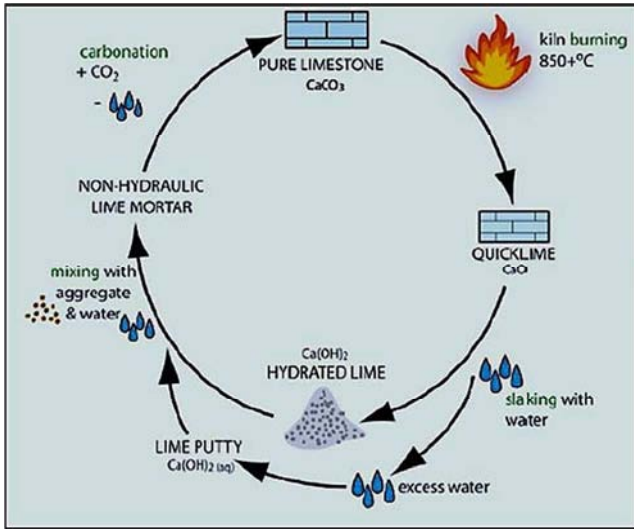


Figure 1. Lime cycle.

During operation process of lime mortars, some conservators observed non-adhesion in the mortars or non-sufficient adhesion between lime and other components of mortars, those reasons push some conservators to add unsuitable materials for conservation works such as black and white cement in restoration. The problems of using cement are various between salts efflorescence's in the presence of any moisture source, the high tensile strength on the historical layers and irreversible deterioration of archaeological surfaces and layers.

2. Definition of Lime Through the Historical Arabic Manuscript

They identified "lime" as "Burning stones powder, slaked by water and mixed with sand to get Khafki (Roman cement). That was the mortar, which they used in water tanks, water suppliers, for rendering plastering in wet environment, for roofs treatments and different other uses. The component of Roman's cement; "Khafki" is slaked lime, volcanic ash or powder of burnt brick and sand with different ratios. The ash of volcanic called Pozzlan. There are two kinds of pozzlan; natural and artificial. The best addition to lime to get the best results called Pozzlan relating to Pozli city in Italy from Roman Era. These are the best kinds of lime, which can be taken from the most solid stones like marble. Some countries that do not prefer marble mortars use lime mortars, for plastering works [6].

3. Specification of Extraction Lime and Sources Through the Historical Arabic Manuscript

The manuscript confirmed that Recent stones are better than old stone used for lime manufacturing in some places, as

the lime from wet quarries is better than dry ones [7]. The wet lime comes from coastal environment is called quick lime from the dry seashells and this may be the reason for naming of this kind of lime they did not make any powdering of the lime. Sometimes they use it without powdering, they mix it with hemp and they added oxides to get the required colour whether in building with stones or in ceiling.

The lime which was manufactured from stone shreds or marble shreds from the top of mountains, from rivers or from plains and all those kinds have white color.

According to other resources to get best properties there are some specification for choosing best qualities like hard, heavy and fine aggregates and should be integrated together. They confirmed that calcareous gravel and marble gives good sources.

4. Kinds of Lime

There are two kinds of lime divided into Air lime and Hydraulic lime.

4.1. Air Lime

There are different kinds of Air lime, these kinds dry and become hard out of water, the first one called Sulatani lime (fat lime), the second is poor lime (non-fat lime) the third: Dolomitic lime, here is some details about each type, Air-lime mortars with or without pozzolanic components were largely used in the past. Due to natural or accidental degradation, the application of repair mortars it is often necessary Repair mortars have to be compatible with the masonries of historic buildings and should be as durable as possible (without compromising the previous compatibility condition) [8].

4.1.1. Sultani Lime (Fat Lime)

It is pure lime, and out of impurities. It contains CaO (Pure) during slaking process huge heat emits and it swells into two or three times increasing more than the original volume.

4.1.2. Domestic Lime (Non-Fat) Poor Lime

This type of lime has grey colour. It contains approx. (15-30) % of its weight impurities, it does not swell as well as in Sultani lime.

4.1.3. Dolomitic Lime

The third one always used in buildings mortars. It contains large amount of magnesium carbonate that reduce swelling during slaking process, because of that it decreases its volume during workability but it is characteristic by its solidness in mortars which have double hardness of Sultani lime, all previous depend on the additives which will be added to the mortar, When carrying out a cultural heritage conservation project on highly degradable materials, the ideal course of action is to replace the damaged material by another of the same or similar characteristics in all, the carbonation process of the lime mortars studied during the 6 months subsequent to their preparation is determined both by the composition and the type of lime used. The best results were obtained with lime putty, which was almost always the dolomitic type [9]. (table. 1) shows chemical specification of building lime [10].

Table 1. Chemical specification of building lime.

Chemical Prosperities	%					
	Hydraulic lime		Fat lime		Magnesium lime	
	Quick lime	Slaked Lime	Quick Lime	Slaked	Quick lime	Slaked
Minimum CaO +MgO	75	70	85	85	85	85
Maximum MgO	5	5	5	5	—	—
L O I Loss on Ignition	5-7	—	5-7	—	5-7	—
SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃	5-25	5-25	>5	>5	>5	>5
Maximum Residual after slaking	5	5	5	5	5	5
Maximum CO ₂	5	5	5	5	5	5

4.2. Hydraulic Lime

The first records of hydrated lime mortars with clayish additions date back to constructions in Babylon from 3000 B. C [11]. This kind setting in water, its quantity increased after mixing with water, because the limestones are the source of lime contains silica and Alumina those two components as well as mixture water improve mortar workability, for these reasons they use it in building foundation and bridges that built in moist environment, Hydraulic limes display an additional mechanical strength due to their hydraulic set. When it compared to fat limes, Hydraulic limes have lower permeability and flexibility and a better resistance to moisture, frost and salt attack [12].

There is a shortage of information about burning lime. In the past, they got lime from sea shell, the process of slaking lime still in presence of water surplus for days or months or years. There was another method of slaking lime by covering dry lime under sand layer. This process called "dry slaking" under water and direct workability for mortars, which process is instantaneous and synchronized with working after mixing with water. These kinds of mortars called "hot lime mortars". They used quick lime with sand through mixing and grubbing by axe, sometimes they put box of water nearby mortar mixtures to help in workability process and they covered working area with shelters, in Zürich slaking process outside the town in a prepared courtyard for slaking after that they transfer lime putty for working area [13].

The process of getting lime was by burning calcareous stones and adding water to the burning lime and they added Pozzlan and sand to get mortars in Italy, they used wood for burning process before using coal which needs hard workers and technicians, because any mistake during burning will cause rocking which will affects badly.

The fatness of lime describes the lime, which have no impurities, so if the lime is pure it will be fat. Sometimes those impurities give good results to mortars when they mix it with well slaked lime. They make some treatment for mortars to get the best workability of the mortars by mixing the mortar with lime impurities and by using fly ash when possible, and that method is still in use in Yemen it took long time more than three days to get best results of the mixture.

5. Lime Burning Process

There are different methods of firing lime, which were by

using wood, shaped straw, and coal and recently by using diesel and gas. There is no problem in burning methods, but what important is to get firing after 850°, the most important is to slake lime in right way to get the best results of mortars, some studies concentrated on slaking in open environment and through mixing it by wooden stick.

The best way for burning lime according to the manuscript by using coal owing to the speed of burning process and the fatness which will occur after burning process, and that fatness increased by increasing the speed of burning process to get fat lime, Calcination temperatures from 850°C to 1200°C can be used to produce natural hydraulic lime from the selected raw material. The calcination at the lower temperatures leads to the formation of a certain amount of amorphous phases and does not allow all available compounds to combine to form hydraulic phases [14].

6. Indicators of Completion of Burning Process According to the Historical Arabic Manuscript

They could know the completion of burning process through whiteness of burning lime and the sonorous of lime when they knock they hears sound like pottery, and it gives heavy rising smoke and heavy dust when they put water on the burning lime.

According to Aref [15]. the stones that used for hydraulic lime need a lot of precautions and special care. The workers should take care of heat. As it should be regular and should not exceed the red heat (cherry colour), because the stones will be changed into glass materials, and if the duration of burning continues the carbonic acid would be raised and the lime becomes heavy and the color changes into black color, the glass layer prevents slaking process and could not give any hardness. Some countries spray water on the stones before burning, they thought the water facilitate burning process, because water stream help in extracting carbonic acid during burning process, for that reason they used iron boxes full of water in the fuel field and they did out puts for steam which will spread in to the kiln.

For increasing lime burning renewing air, for that reason they should keep areas for air streams, which should help extraction of carbonic acid.

7. Recent Slaking Processes of Lime for Restoration Works

Through our work in conservation of historical buildings, we found different methods of slaking lime as follows:

A. The first method is to but lime in built basins and fill it with water, sometimes they make like shelter.

B. The second was to put lime in whether plastic or metal barrels then they fill it with water, the plastic barrels are subjected to expanding owing to the high temperature and raising steam.

C. The third method was to spray water in shallow basins, and transfer it into barrels which were filled with water, then they sieve it to get lime putty. There were two main problems in three methods the first was the shortness of slaking duration that affects badly on the quality of lime, the second leaking of follow -up expose lime to drying and cracking in slaking position because of that, lime putty never gives required properties. (Figure. 2). Shows one of the customary methods in slaking lime which was widely used by conservators of antiquities and historical buildings, the summery of that methods are to put lime in metal barrels they put lime and add water they keep it for short or long time in open environments (Figure. 3). which affects badly on the properties of lime and gives a chance to quick dry the lime after that became non-usable and loose his slaking properties and cracked (Figure. 4).



Figure 2. Slaking lime in metal barrels without covering.



Figure 3. Keeping lime in open environment after slaking.



Figure 4. Non-usable lime owing to the cracked lime after losing all water content.

8. Slaking Lime According to the Historical Arabic Manuscript

Slaking lime for Khafki (Roman cement) by making excavation for the required amount of lime and they cover it with sand approx. two foots and they put enough water in all direction in that case lime completely dissociated under sand, when they observe smoke out of the cracks of sand (Figure. 5-6). the lime in that case become fat lime (Figure. 7). For slaking process, they spray water above lime of times by the suitable amount of water and they did not put water one time because this action will affect badly on the properties of the slaked lime.

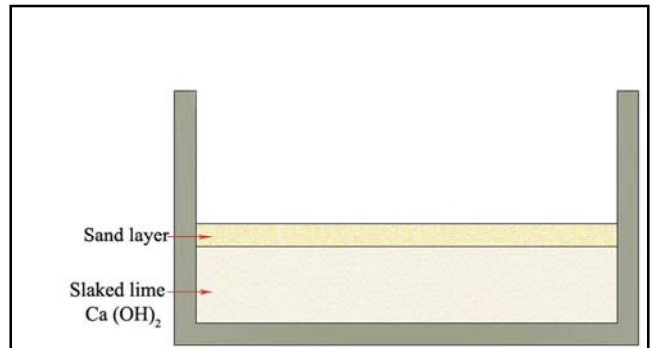


Figure 5. Slaking process of lime according to the historical manuscript.

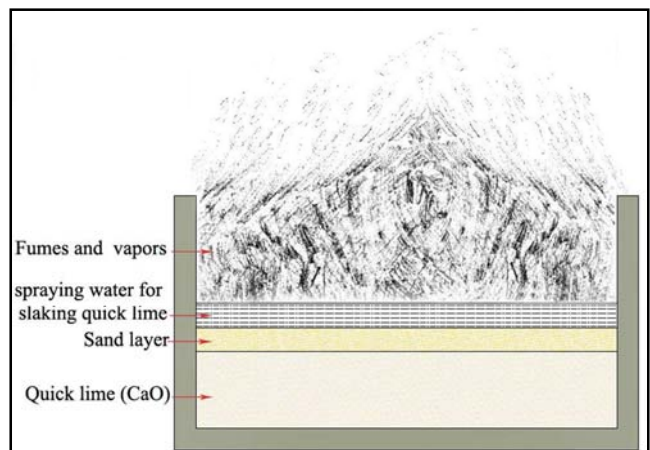


Figure 6. Dissociated lime in water under sand after slaking.

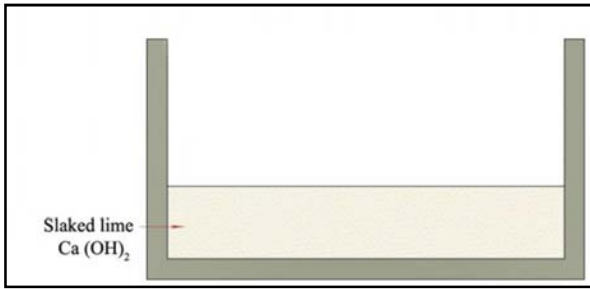


Figure 7. Slaked lime (fat lime) after finishing slaking process.

8.1. The Duration of Slaking Process According to the Historical Manuscript

If they left lime for one or two years under slaking, it would give good properties, that means they already have places for slaking. Because of the long period, the lime becomes very white, viscous and like cream. If they move it with stick, it would be very difficult to move. That kind of lime used in plastering work, for Khafki works (Roman cement) and in wet environment. They assured that lime would have enough periods after slaking because any instant lime slaking may result in some un-slaked parts that will badly affect the mortar properties and will dry as bulk in the mortar after application, it will be like dust after drying owing to non-slaking pieces, which will give bad properties of the work.

8.2. Identification of Completion of Slaking Lime Process

According to the historical manuscript, they could identify completion of slaking process and saturation by water through implanting stick into the lime under slaking. If the stick stopped during implanting process due to some un-slaked shreds of lime, and without polluting the stick with lime, in that case they know that there were some parts did not slake and there is a problem in slaking process related to the incomplete saturation with water. On the contrary, if the stick went into the slaked lime without any crippling and the stick polluted with lime in that case they know that lime saturated with water and slaked in right way.

9. Slaking Lime According to Trosaad [15]

Trosaad presented three methods for slaking lime:

(1) The First One

After burning lime and extracting it from the cline, they put enough amount of water until it becomes lime putty. This was the ordinary method to slake the lime that called "fatty the lime". In this method, dissolve more than they want, because they put huge amount of water like milk subsistence, after that they put it in an excavated well, closed edges with building boundaries, after that the lime become frozen in a short time. They covered it with sand or dust to protect it from air. Because if it reacts with air, the upper layer of lime will become calcium carbonate. Moreover, if they leave the lime for a long time it will acquire good properties. This opinion is

not right, and if it becomes short, it will not affect the properties of lime. According to his experiments, he did not take any results to support this opinion because he used samples of lime slaked for a long time did not give him good properties after exposing to air, the frozen of lime as a result of three reasons:

A. The soil in the site of slaking lime absorbs some water of slaking water.

B. The steam of slaking process rises up.

C. Mixing lime in the bottom of the wet excavation especially in winter causes lime frozen owing to the cold water and the weather already help the frozen process.

To confirm his theory, he brought slaked lime from four years ago and brought, recent burning lime and put it in water to take lime putty he got good results from the recent one but the old one needs water more than one time to become lime putty.

(2) The Second Method

To dunk un-slaked lime in water, for one time, for seconds, after that they extract it from water before dissolution and before transferring into very soft and deliquescent material like flour, then they keep it in palace away from any humidity sources in the process of dunking by putting lime after crushing it like oval shape in frail. The first using for this method in 1777 AD, at that time they considered it discovery and considered it one of secrets but that method did not give the ideal properties.

People in Strasburg used little different method by dunking lime in tinsplate basins, then they put lime and quarter of lime amount water, then they test the process of slaking by metal stick to make sure that water reached all lime. If they find some lime does not saturated with water, they add little water to slake it this test after steam stopping sometimes un-slaked pieces relating to the high burning temperature.

(3) The Third Method

By exposing lime after burning process to wet airflow. The lime in that case is gluttonous to absorb water from air that means the dissolved water in air absorbed by lime (Figure. 8). There are disadvantages for that method because slaking process is very slow and there is no rising smoke or heat, the duration for this method very long, this method called slaking by air and the lime become non-usable and deteriorated.

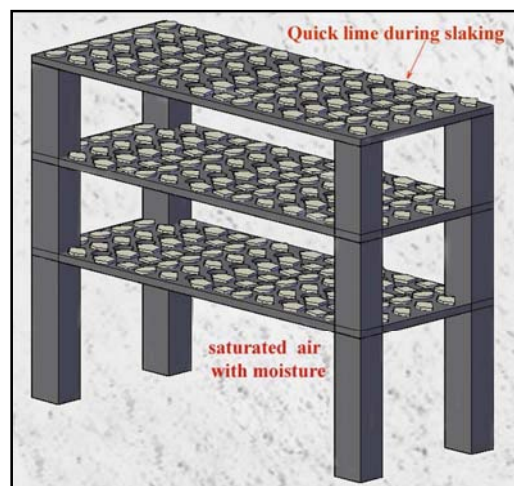


Figure 8. Slaking lime by absorbing dissolved moisture in air.

10. Slaking Process According to Aref [15]

Aref presented three methods of slaking lime as follows:

(1) The First Method

After burning lime, they put it under shelters prepared for this purpose to protect lime from saturated air with moisture, they keep it subjected to air for slaking under wet air action. The lime after slaking becomes available for mortars working, this method used in case of fat limes, for non-increasing of volume in this lime it was costly, so they could solve this problem by making Multi-storey sheds which was movable to help putting and removing lime easily, in this method the thickness of lime during slaking (0.30)meter to help in slaking process and they should move lime above shelters until transferring into like soil, the duration of slaking process was different according to the kind of lime, sometimes they keep lime for weeks or months or one year and this the common period for slaking by this method.

(2) The Second Method

They put burnt lime in prepared place and they spray water gradually and they mix it, the lime converted in to the lime that was available to work in mortars this method was wide working in Egypt, they should spray water on lime daily before working and mix it. The workers should remove impurities like gravel and other impurities. They should make sure of all lime completely slaked. Because un-slaked parts will dry in the buildings and will affect badly on the mortars properties, in some countries European countries they covered the slaked lime by sand and they keep it to the next year, the tests confirmed the slaked lime that still slaked under sand for at least two days is better than slaked lime soon.

(3) The Third Method

They put lime in prepared basins with sufficient water for lime dissolution. When the heat stopped, they transfer it to another basin until completely deposition and became like putty and available to use, this method suitable for fat limes, and their volumes increases more than any limes so they advise use it more than any other lime and to use it in case of Hydraulic lime. (Figure. 9). slaking process by putting lime in prepared basins with sufficient amount of water. (Figure. 10). lime after slaking process.

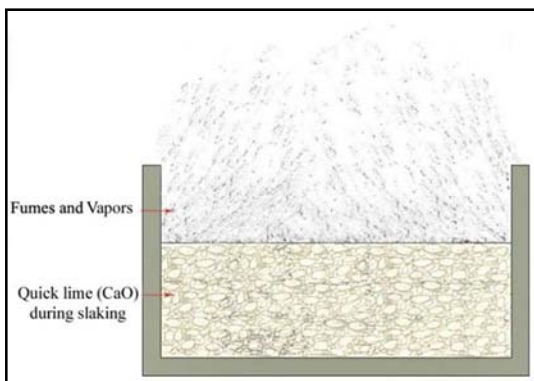


Figure. 9. Slaking lime by putting lime in prepared basins with sufficient amount of water.

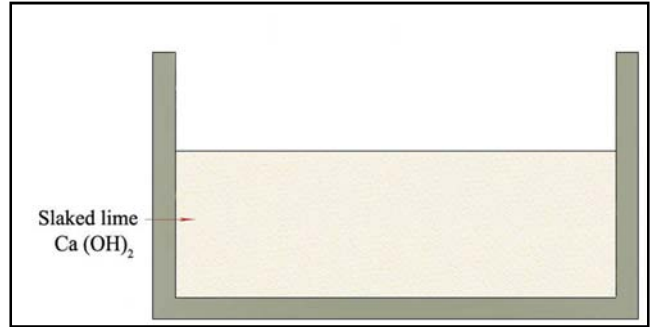


Figure. 10. Slaked lime (lime putty).

11. Adequate Amount of Water for Slaking Process

The amount of Water for slaking process should be compatible with lime amount. The experiments confirmed that the increasing water weaken lime properties in mortars, but if they need to use lime in plaster or white wash there is no problem of being white wash the workers used to but lime in receptacle and put lime until being saturated with water and smoke and pebbles stopped.

They always try to remove any gravel out of the bottom by washing the lime by little water. After filling the pot, they covered it with mat to prevent from dust and other impurities. The basins of slaking lime should be out of the working areas, they should keep it at least three or four days in order to get fat lime m they cut it with shovel and axe, the slaked lime by this way called Sultani lime because of burning lime and other solid and blue color limestone.

Some quarries like El-Max in Egypt the one Cubic meter needs 500liter of water for slaking and if they want to transfer lime to lime putty they need another 500 liters more, the weight of Cubic meter for the stones before becoming lime 846 KG, the weight of Cubic meter from the soft lime 742 KG, and from lime putty 1500KG.

For the fine works, they used the white stone pieces and the cleaned ones they burn it by wood or straw instead coal of but for shaped straw [15].

12. Conclusion

Lime is the most important component of mortars, which used in the conservation of historical buildings, or any archaeological materials built by lime. For this reason, conservator should slake lime in right way to get good results. Those resources presented different methods of burning and slaking lime. The process of slaking depends on many factors like; kind of lime, usage of lime after slaking and other considerations. Some resources confirmed that best results can be obtained by prolonging the duration of slaking. There is consensus about slaking under sand. The best method in the past for burning was by coal owing to the high temperature during burning process. The best kind of lime comes from marble. We should improve those methods by experimental studies to get good properties by adding volcanic ash. We

should use lime and prevent black and white cement in restoration process, which have caused many problems in historical sites.

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